Colorado State University
Center for Geosciences/Atmospheric Research (CG/AR)
Quarterly Report No. 22
by T.H. Vonder Haar and Collaborators

Reporting period: July 1 – September 30, 2011

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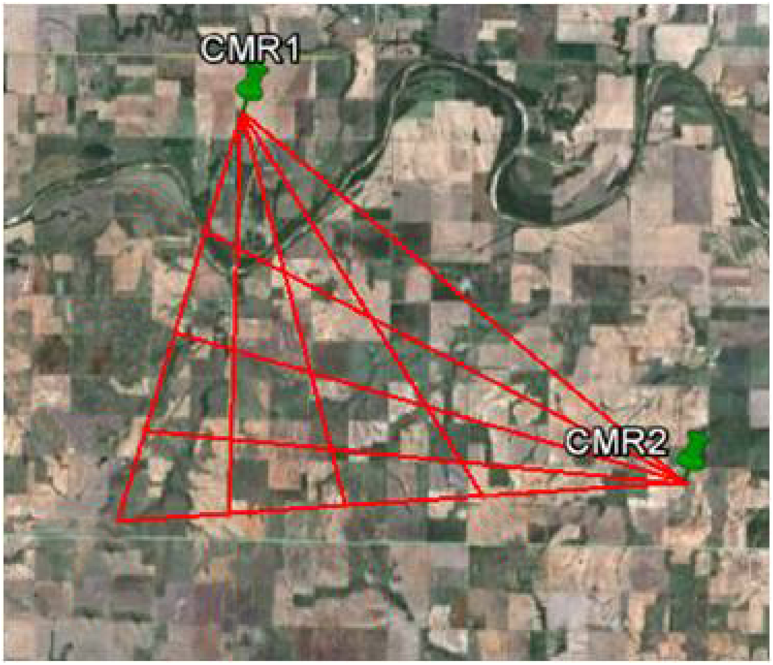

Map showing the location of the radiometers during the HUMEX11 field experiment. CMR2 was located at the DOE-ARM SGP Central Facility.

From the research of Mr. Swaroop Sahoo and Prof. Steve Reising. See details of their work under the Urban and Boundary Layer Environment Research Theme.

Report Documentation Page

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Overview

The Center for Geosciences/Atmospheric Research at Colorado State University continued this quarter with five research themes: Hydrometeorology; Clouds, Icing and Aerosols; Urban and Boundary Layer Environment; Remote Sensing of Battlespace Parameters; and Technology Transfer. In this quarter, six refereed papers were accepted or submitted by CG/AR researchers and supported students. Eleven graduate students were supported. Interactions between CG/AR scientists and DoD-affiliated personnel continued as usual, including discussions with representatives of ARL/BED, ERDC, CRREL and AFWA.

Cross-cutting research to understand the distribution and behavior of water vapor in gaseous, solid and liquid forms in the atmosphere continued. The analysis of aircraft observations from the CLEX experiments was finalized, with clear impacts on aircraft icing hazards and DoD modeling approaches. CG/AR research on the vertical distribution of cloud water and ice showed further connections between aerosol distribution, cloud microphysics, and mesoscale weather systems. Satellite-sensed water vapor and cloud vertical hydrometeor profiles were investigated to attack the traditionally difficult problem of estimating cloud base in data-denied regions, a topic of particular interest to UAV operators. Several encouraging relationships were discovered. Two inexpensive passive microwave radiometers, fabricated at CSU, were deployed in a field experiment to retrieve water vapor distribution at very high spatial resolution (cover photo).

The environment near and within Earth's surface can be better characterized in an acoustic, aerosol and soil moisture sense due to CG/AR-sponsored research conducted this quarter. High resolution topography coupled with past behavior of soil moisture are being used to map soil moisture on scales of meters. The impact of dam failure is being studied for possible inclusion into the TREX surface hydrology model. A 2-D spatial autoregressive model to support acoustic propagation predictions was developed and is being expanded to three dimensions. Soldier health can be influenced by airborne toxic substances in the battlespace, and CG/AR researchers are coupling surface aerosol measurements with meteorological modeling to track the flow of toxic substances through the atmosphere.

Mr. John Forsythe
CIRA Research Associate

For more information on the DoD Center for Geosciences/Atmospheric Research at Colorado State University, please access our web page at http://www.cira.colostate.edu/research/dod/geosci.php

Colorado State University
Center for Geosciences/Atmospheric Research
Scientific Interactions May 2006 to Present

- Sonia Kreidenweis and Kelley Johnson with Doug Westphal, Piotr Flatau, and Marcin Witek (NRL/Monterey)
- Tom Vonder Haar and others with Mr. Robert Brown (ARL)
- Tom Vonder Haar and CG/AR researchers with Dr. James Cogan (ARL)
- Milija Zupanski and others with Jeff Tilley (UND)
- Andy Jones and Cindy Combs with Gary McWilliams (ARL) and Li Li (NRL)
- Steven Fletcher with Carolyn Reynolds (NRL), Dale Barker (NCAR), Brian Ancell (Univ. Washington), Ron Errico and others (NASA Goddard), and international colleagues
- Stan Kidder with Arlin Krueger (Univ. Maryland-Baltimore County)
- Steven Fletcher with Clarke Amerault (NRL)
- Andy Jones, Laura Fowler, Steven Fletcher, Manajit Sengupta, Scott Longmore, Tarendra Lakhankar, and Curtis Seaman with Dale Barker, Hans Huang, Qingnong Xiao, Jenny Sun, and Zhiquan Liu
- Large and small group interactions at the Annual Review, held at CSU/Fort Collins, including:

  Tom Vonder Haar, Ken Eis, Loretta Wilson, et al. with DoD Review Panel and invited attendees

  Adam Kankiewicz with Pam Clark (ARL) and Ted Tsui (NRL)

  Stan Kidder and Jeff Jorgeson (ERDC)

  John Forsythe with Ted Tsui (NRL)

  Pierre Julien and James Halgren with Jeff Jorgeson (ERDC)

  Sonia Kreidenweis with Ron Pinnick (ARL)
- Steven Fletcher with Profs. Nancy Nichols and Alan O'Neil (Data Assimilation Research Centre, UK)
- Steven Fletcher with Dr. Amos Lawless (Department of Mathematics at the University of Reading) and Dr. Eric Andersson (ECMWF)
- Tom Vonder Haar with Patricia Phoebus, Joe Turk, Jerry Schmidt, Nancy Baker and Craig Bishop (NRL)

- Tom Vonder Haar with Philip Durkee (NPS)
- Mahmood Azimi with Mike Mungiole, Alan Wetmore, John Noble, Pam Clark, Sandra Collier and Dave Marlin (ARL)
- Curtis Seaman with Nancy Baker and others (NRL)
- Andy Jones and Steve Fletcher with Dale Barker (NCAR); Dennis Garvey, Jim Cogan, Alan Wetmore (ARL); Tim Nobis (AFWA)
- Yoo-Jeong Noh and Curtis Seaman with David Hudak (Environment Canada)
- CG/AR researchers and graduate students with James Cogan (ARL/WSMR)
- Steve Miller and Andy Jones with Michael Wynne (Secretary of the Air Force)
- Andy Jones with Gary McWilliams (ARL)
- Andy Jones with Dr. Ye Hong (Aerospace)
- Andy Jones with Mr. John Eylander (AFWA)
- Andy Jones with Dr. White (NOAA/ESRL)
- Andy Jones and Steven Fletcher with Bob Dumais (ARL)
- Andy Jones with Gary McWilliams (ARL)
- Andy Jones with Dr. Tom Greenwald (Univ. Wisconsin)
- Michael Coleman with Rick Shirkey (ARL)
- Andy Jones with Brian Skahill and Mike Follum (ERDC/CHL)
- Andy Jones and Adam Carheden with Rick Shirkey
- John Forsythe and Eric Guillot with Bob Dumais (ARL-White Sands Missile Range)
- John Forsythe with Lt. Col Vincent Rees (AFWA)
- Andy Jones with James Cogan (ARL)
- Andy Jones with Gary McWilliams (ARL), George Mason (ERDC), Jim Cogan (ARL) and Dr. Li (NRL)
- Stan Kidder with Prof. Phil Durkee (NPGS)
- Sonia Kreidenweis with Prof. Cathy Cahill (Univ. Alaska-Fairbanks)
- Andy Jones with John Eylander (AFWA)
- Andy Jones with Susan Frankenstein (CRREL)
- Sam Atwood with Pam Clark and others (ARL)
- Andy Jones with John Eylander (AFWA)
- Prof. Jeff Niemann with George Mason (GSL/ERDC)

- Yoo-Jeong Noh with Peter Rodriguez (Environment Canada)
- Yoo-Jeong Noh with Dr. G. Liu (Florida State University)
- Andy Jones, Tom Vonder Haar, Stan Kidder, Sonia Kreidenweis and Sam Atwood, Steve Reising, John Forsythe, Loretta Wilson with Dr. James Cogan (ARL), 3-day visit to CG/AR
- Sonia Kreidenweis with Prof. Cathy Cahill (Univ. Alaska-Fairbanks)
- Sonia Kreidenweis with Dr. Jeff Reid (NRL-Monterey)
- Andy Jones with Dr. Rick Shirkey (ARL)
- Sam Atwood at NRL-Monterey (hosted by Dr. Jeff Reid)
- Andy Jones, Sue van den Heever and Rob Seigel with Dr. Robert Haehnel (Army Cold Regions Research and Engineering Laboratory)
- Prof. Steve Reising with Dr. David Turner (NOAA National Severe Storms Laboratory)
- Andy Jones and Stan Kidder with Dr. Jeffrey Cetola and Mr. Steve Rugg (AFWA)

Research Theme: Hydrometeorology

Administrative

Kevin Werbylo, a first semester graduate student pursuing a Master's Degree in the Department of Civil and Environmental Engineering at Colorado State University, has been selected to work on this project under the direction of Dr. Jeffrey Niemann. Kevin's official start date on the project was August 15.

Research activity and/or results

Dr. Andrew Jones
Continued activities related to support for the DWSS MIS Performance Team (MPT) land team.

Collaborated with Mr. Gary McWilliams at ARL/BED, Mr. John Eylander at ERDC/CRREL, and with other Army and USAF individuals regarding the SMAP Applications Workshop, ERDC/USAID research planning, and the Army Environmental Military Intelligence System (AEMIS) developments.

The Data Processing and Error Analysis System (DPEAS) was updated to version 3.x, to enable 64-bit processing, and use of HDF5 and netCDF4 libraries using an up-to-date fortran compiler. A DPEAS documentation summary, users' guide, programmers' guide and a cross-sensor processing environment guide were prepared.

Hosted Dr. Jeffrey Cetola and Mr. Steve Rugg (AFWA) on September 28 and gave a presentation on collaboration opportunities.

Prof. Pierre Julien and Andrew Steininger
Andy has continued his modeling research concerning dam break and dam overtopping. Many successful simulations have been run modeling dam overtopping and flood wave routing. The results of these simulations are being compiled, analyzed and prepared for presentations and outside review. Additionally, model simulations are continuing to be run. The possibility of more explicit dam failure modeling with TREX through further research and model code modification is also being examined for the purpose of future research proposal.

Prof. Jeffrey Niemann and Kevin Werbylo
The overall objective of this project is to evaluate the use of EOF-based methods for estimating ponded areas of the landscape in tactical decision aids such as MyWIDA. In previous portions of this project, purely empirical EOF methods have been developed and tested. The goal of the present phase of work is to test the performance of a physical interpretation of the EOF method, which is called the Equilibrium Moisture from Topography (EMT) Model. This objective will be achieved by evaluating the following: 1) the ability of the model to reproduce spatial variations of soil moisture, 2) the ability of the model to reproduce spatial and temporal variations of soil moisture, 3) the performance of the model when available data is limited, and 4) the performance of the model when applied at different scales. In all cases, the performance will be compared to the existing EOF method.

Kevin has been working to gain an understanding of the current state of soil moisture research. This effort has included reading journal articles and collaborating with members of his research group. Kevin also has been working to develop the skills necessary to apply the EMT model. Development of these skills has included studying and understanding the derivation of the mathematical model, understanding the key assumptions used in developing the model, understanding how the model is executed using MATLAB, and developing the necessary programming skills to effectively use MATLAB.

To date, Kevin has used the EMT model to generate soil moisture patterns at the Tarrawarra research catchment using newly optimized parameters as well as parameters optimized by previous researchers. In each of the cases mentioned, the parameters were optimized using known soil moisture observations at the Tarrawarra catchment. This process served as an introduction into what will need to be done to begin the evaluation procedure of the EMT model.

Travel

None this period.

Equipment/systems status

Nothing to report this period.

Research Theme: Clouds, Icing, and Aerosols Effects

Administrative

None this period.

Research activity and/or results

Dr. Yoo-Jeong Noh

C3VP/CLEX-10 and CLEX-9 aircraft data analysis to obtain vertical liquid water distributions in mixed-phase clouds

The vertical distribution of liquid and ice water content and their partitioning is studied using CLEX-9 and CLEX-10 in situ aircraft probe data. Using the analysis of radar images and detailed flight track, 41 cases were selected. Various microphysical properties in midlatitude mixed phase clouds were examined and categorized into four different cloud types depending on their vertical extents and altitudes. Liquid water paths have a range from near zero to ~275 g m^{-2}, total water paths have a range from near zero to ~600 g m^{-2}, and cloud top temperature ranging from -2 to -39°C. It is found that both the vertical distribution of liquid water within a cloud and the liquid water faction (of total condensed water) as a function of temperature or relative position in a cloud layer are cloud type dependent. In particular, it is found that the partitioning between liquid and ice water for mid-level shallow clouds is relatively independent on the vertical position within the cloud while it clearly depends on cloud mean temperature; liquid water fraction is ~100% at temperatures warmer than -10°C. For synoptic snow clouds, however, liquid water fraction increases with the decrease of altitude within the cloud. While the liquid water fraction in synoptic clouds also decreases with lowering temperature, its magnitude is only about 50% at temperature near 0°C.

We completed a manuscript in collaboration with Dr. Liu (Florida State University) and submitted it to *J. Appl. Meteor. Climatol.*

A JGR paper, "Comparisons and analyses of wintertime mixed-phase clouds using satellite and aircraft observations by Noh, Y. J., C. J. Seaman, T. H. Vonder Haar, D. R. Hudak, and P. Rodriguez" was published (see the Technology transfer section).

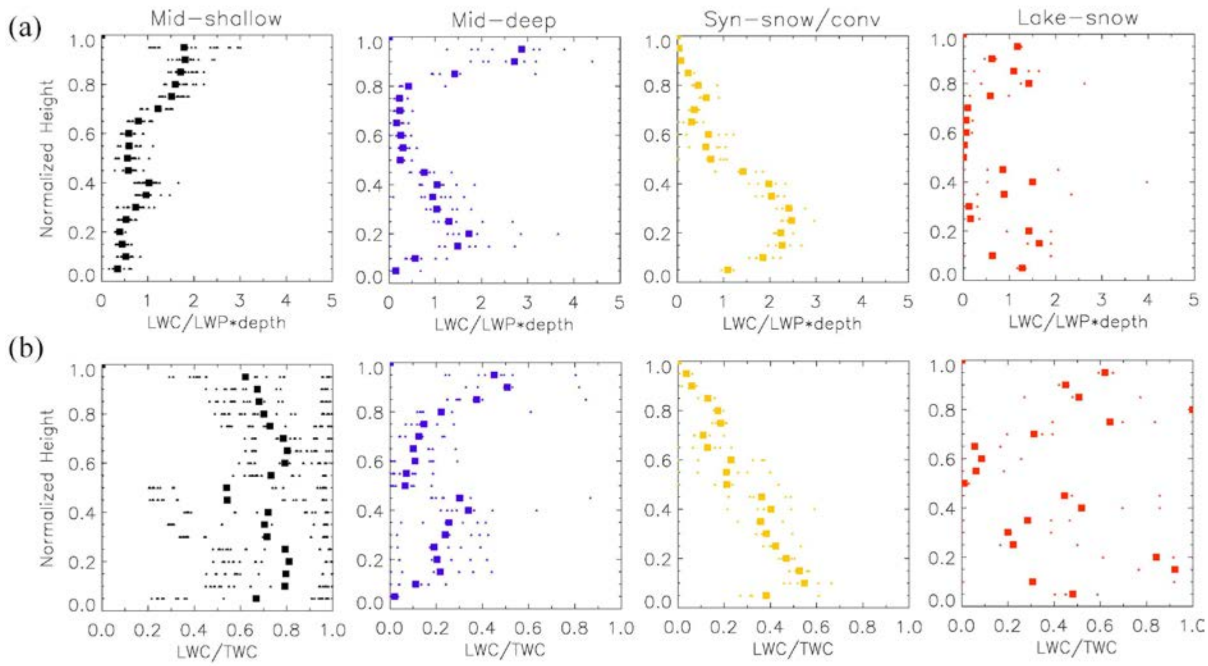

Figure 1. Vertical distributions of (a) LWC normalized by LWP times cloud depth and (b) the ratio of LWC/TWC for each cloud category, respectively. The greater symbols are the mean profiles in corresponding cloud categories. Vertical axis is normalized, so that cloud base is 0 and cloud top is 1 under the "normalized height" in every case. Each profile was 3-point moving averaged per 0.05 normalized height and zero values were not plotted.

Dr. Curtis Seaman

The revised manuscript titled, "Comparisons and analyses of aircraft and satellite observations for wintertime mixed-phase clouds" was accepted for publication by the Journal of Geophysical Research (see Technology Transfer).

A second manuscript lead by Yoo-Jeong Noh was submitted to the Journal of Applied Meteorology and Climatology. This second manuscript, titled, "In situ aircraft measurements of the vertical distribution of liquid and ice water content in midlatitude mixed-phase clouds" focuses on the average properties of clouds observed *in situ* during C3VP/CLEX-10. Clouds were classified into four groups, Lake Effect Snow, Deep/Synoptic Snow, Shallow Midlevel and Deep Midlevel. Cloud properties compared between these classifications included liquid and ice water paths, cloud base and top temperature, cloud base and top height, and liquid fraction (percentage of total water content that is liquid). he relationship between liquid droplet effective radius and liquid water content was explored, as well as how the liquid water content profiles compared to the theoretical adiabatic liquid water content profiles.

Results show that mid-level clouds have a liquid water content profile that is nearly adiabatic, while lake effect and deep/synoptic snow cases do not. Deep/synoptic snow cases have a higher liquid fraction in the lower portion of the cloud, while mid-level clouds have the highest liquid fraction near the top of the cloud. There is evidence to suggest that the liquid fraction is a function of the mean temperature of the cloud.

John Forsythe
Editorial revisions on the journal paper "How Total Precipitable Water Vapor Anomalies Relate to Cloud Vertical Structure" (Forsythe, Dodson, Partain, Kidder and Vonder Haar authors), which was submitted to the AMS *Journal of Hydrometeorology* in May. The paper was accepted for publication.

Collaboration with Eric Guillot on his journal paper "Evaluating satellite-based cloud persistence and displacement nowcasting techniques over complex terrain" (Guillot, Vonder Haar, Forsythe, Fletcher authors), which encapsulates his M.S. thesis. The paper was submitted to *Weather and Forecasting* and was accepted in early October contingent on minor revisions.

Further development of extended cloud statistics results via along-track data denial experiments. An example data denial result showing is shown in Figure 2.

John Haynes
Began spin-up work on the extended cloud statistics project, which aims to derive three-dimensional cloud structures from (1) detailed two dimensional information obtained from CloudSat (i.e. along-track, vertically resolved cloud structure), and (2) the surrounding two dimensional horizontal cloud structure obtained from passive sensors (i.e. along-track, cross-track). The project aims to demonstrate that it is possible to combine these sources of information to provide useful off-track vertical cloud information.

Most of the spin-up work involved determination of the best way to express the weighting applied to observed CloudSat cloud types. The weighting used in the calculation of cloud base (or top, thickness, etc.) should be greater for closer clouds, and smaller for distant clouds. In practice, we consider these weights to be inversely proportional to the standard deviation of the cloud height as calculated for clouds of the same type occurring at some distance from the target.

The cloud weights were used in a data denial experiment (see Figure 2) that demonstrated the ability of this method to outperform the relatively unskilled 'nearest neighbor' method, which simply assumes that the cloud height at a target point is identical to that of the nearest point with the same observed cloud class.

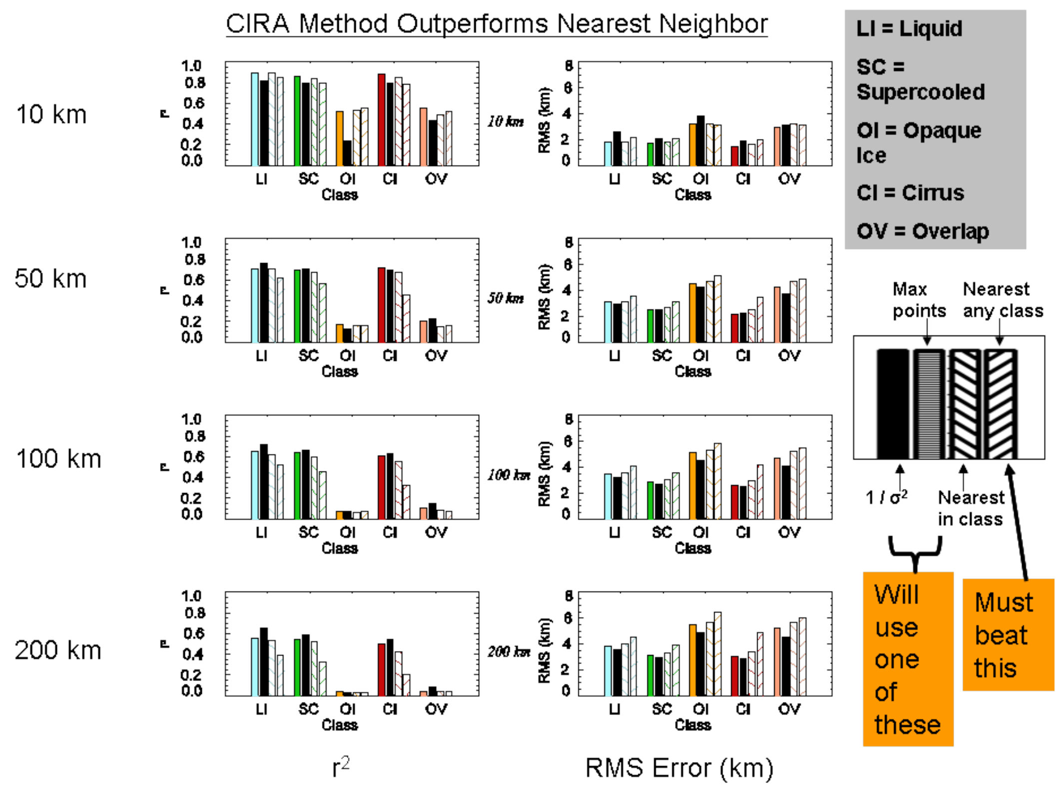

Figure 2. Data denial results for four exclusion ranges (10, 50, 100 and 200 km) for July 2009, MODIS GSIP classes. Results are shown for 5 cloud types (liquid, supercooled, opaque ice, cirrus and overlap (ice over liquid). Left panel shows the coefficient of determination, right panel is the RMS error in km. Results shown for uppermost layer of cloud. Within each exclusion range and per class, 4 results are shown. The leftmost two bars are the CIRA method of using more distant predictors within the same cloud class, while the right two bars are nearest neighbor techniques. The results in the leftmost two bars are hypothesized to outperform the rightmost two bars. Results indicate that the CIRA method does outperform the nearest neighbor technique, with greater performance differential at the 100 and 200 km exclusion range.

Travel

Yoo-Jeong Noh participated in the 5th Workshop on Satellite Data Application for Global Environment Monitoring in Gyeongju, South Korea, September 28-30 and presented research results. Her travel was fully supported by the National Institute of Meteorological Research/Korea Meteorological Administration (NIMR/KMA).

Equipment/systems status

Nothing to report this period.

Research Theme: Environmental Modeling and Assimilation

Administrative

None this period.

Research activity and/or results

There was no reportable research activity during this quarter.

Travel

None this period.

Equipment/systems status

Nothing to report this period.

Research Theme: Urban and Boundary Layer Environment

Administrative

None this period.

Research activity and/or results

Prof. Thomas Vonder Haar and Gavin Roy

The research continues to focus on the effect of alternative energy sources on the atmospheric boundary layer, radiative balance, and regional hydrology. Gavin is using NASA's newly-developed Land Information System (LIS) to quantify the near-surface effect of replacing corn crops in many areas across the Midwest with switchgrass and miscanthus crops, grasses that have been found to be on average 50% more effective at being converted into biofuel than corn.

Prof. Sonia Kreidenweis, Sam Atwood and Lauren Potter

Ms. Lauren Potter continued her research toward her ATS M.S. degree. She focused particularly on developing methods for displaying trajectory variables such as precipitation and solar radiation, weighted by either receptor data, by region of origin, and other methods aimed at developing source-receptor relationships. She began to shift focus toward Pacific transport, in order to analyze 20-year time series of observations at Mauna Loa Observatory, to test the tools built for the Baghdad and Afghanistan sites. In his time in the NREIP program and NRL, Mr. Sam Atwood completed analysis of DRUM data from special studies at two southeastern Asia sites, obtained through Dr. Jeff Reid of NRL. He also obtained complementary data sets and used them to develop analyses of source-receptor relationships during the special studies conducted at these sites.

Research accomplishments during this time period:

1. Analysis of DRUM data from Lulin and Dongsha (South China Sea) and Singapore special studies.
2. Computation and analysis of trajectories to special study sites.
3. Initial development of case studies of pollutant, smoke, and dust transport, as seen in the data sets.
4. Further analysis of trajectory variables including precipitation and solar irradiation. Development of methods for data display.
5. Computation and analysis of trajectories to Mauna Loa Observatory.

Prof. Steven Reising, Swaroop Sahoo and Dr. Xavier Bosch-Lluis
Prof. Reising worked on coordinating and managing the HUMEX11 field experiment during July-August 2011 at the Department of Energy (DOE)'s Atmospheric Radiation Measurement (ARM) Southern Great Plains (SGP) site near Lamont, Oklahoma.

Dr. Bosch-Lluis was involved in coordinating the field experiment and addressing various issues of the field experiment as they arose.

Mr. Sahoo led the on-site activities of HUMEX11. The HUMEX11 field experiment involved operating two ground-based water vapor radiometers, scanning in both elevation and azimuth, deployed at two sites, CMR1 and CMR2, as shown in Figure 1. The field experiment was conducted in two phases. The 1st phase was performed from 07-July-2011 to 20-July-2011. The 1st phase had to be stopped due to an extended period of unusually hot weather with daytime temperatures in excess of 111°F every day. After some respite from the unusual heat wave, the 2nd phase of the experiment was performed from 3-August-2011 to 13-August-2011, during which data was recorded at both CMR1 and CMR2.

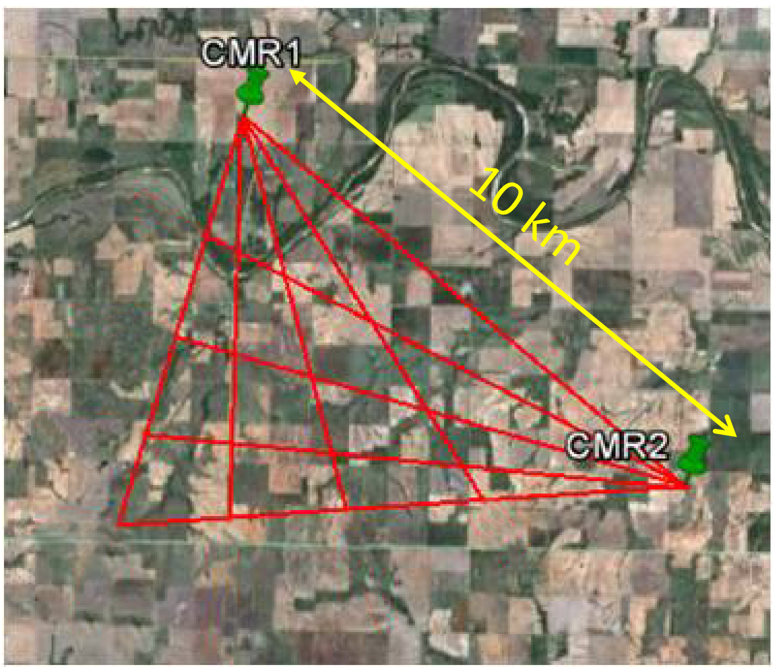

Figure 3. Map showing the location of the radiometers during the HUMEX11 field experiment. CMR2 was located at the DOE-ARM SGP Central Facility.

The quality control of the radiometer data recorded during the field experiment has been initiated and should be completed in the next quarter.

Prof. Mahmood R. Azimi-Sadjadi and Soheil Kolouri
This quarter's research was mostly focused on the following items:

(a) Developing a rigorous model for the dynamic of the process (state evolution equation), using spatial dependence among neighboring cells. This was needed due to the lack of an informative model for the state evolution in our previous UKF-based acoustic tomography formulation. The details of the process is as follows:

- A 2-D spatial autoregressive (AR) model [1] was fitted to the simulated data as the model for the dynamic of the process.
- The UKF-based acoustic tomography formulation was modified to match the new model for the dynamic of the process.
- The UKF-based method was tested with this new model and the results have found to be much improved compared to the simple random walk model.

(b) Investigating the temporal dynamic of the simulated data, in order to fit an appropriate temporal AR model to each cell. This work was done to examine if we need to enter the temporal dependency in addition to the spatial dependency to our modeling.

- ITSM 2000 [2] which is an interactive time series modeling package for personal computers, was used to fit the AR models to the simulated data.
- The results show a strong time dependency for each cell which encourages us to employ a spatial-temporal dependency in our model.

(c) Generating three new synthetic datasets to test our algorithms on more datasets, and have a more accurate estimate of the performance. These datasets have the following characteristics.

- A fractal Brownian motion (fBm) based model [3] was used to simulate the 2D-wind and temperature profiles in space and time, with different values for the consistency coefficient of the fields.
- The simulated dataset contains the same, 500 snapshots of wind velocity and temperature in an area of size 300m*440m (same area as that in the STINHO dataset), like the previous data set we generated in the previous quarter.
- 8 transmitters and 12 receivers were used as in the actual experimental setup for the STINHO data collection (see Figure 4). The time of arrivals (ToA's) were then calculated for all possible paths.

2-D Spatial AR Model and Results

Two dimensional (2-D) spatial AR models for temperature and wind velocity components at the $[m,n]$'th cell and at time k are defined as following ($m,n>1$):

$$\begin{cases} x_T[m,n,k] = -\sum_{i=-1}^{1}\sum_{j=-1}^{1} a^T{}_{i,j} x_T[m+i,n+j,k-1] + \omega_T[m,n] \\ x_\alpha[m,n,k] = -\sum_{i=-1}^{1}\sum_{j=-1}^{1} a^\alpha{}_{i,j} x_\alpha[m+i,n+j,k-1] + \omega_\alpha[m,n] \\ x_\theta[m,n,k] = -\sum_{i=-1}^{1}\sum_{j=-1}^{1} a^\theta{}_{i,j} x_\theta[m+i,n+j,k-1] + \omega_\theta[m,n] \end{cases} \quad (1)$$

where $x_T[m,n,k]$, $x_\alpha[m,n,k]$ and $x_\theta[m,n,k]$ are the temperature, wind velocity amplitude and wind velocity angel in the $[m,n]$'th cell at time k; $a_{i,j}$s are the AR model coefficients which are estimated from MSE based on the training data; and ω_T, ω_α and ω_θ are the process noise for each field. Figure 4 visualizes the $[m,n]$'th cell and its neighbors at time k and $k-1$. Note that the AR models are assumed to be decoupled from each other as the phenomena that generate them are independent.

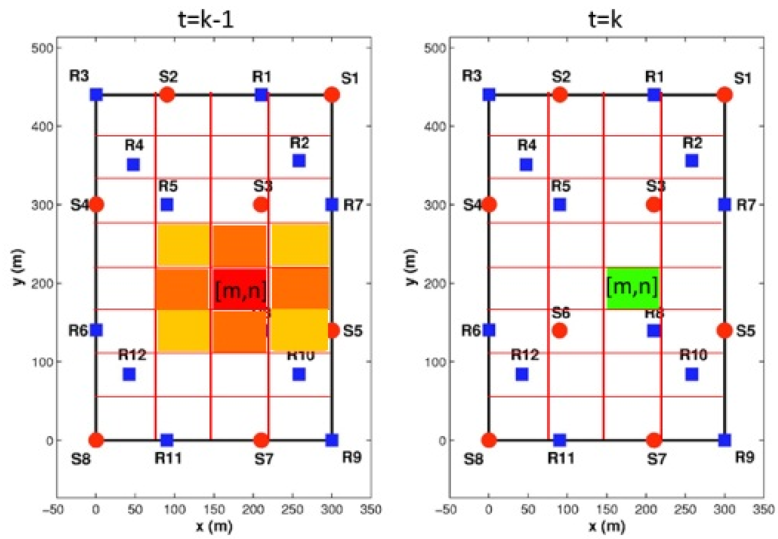

Figure 4. $[\boldsymbol{m},\boldsymbol{n}]$'th cell and its neighbors at time $\boldsymbol{k}$ and $\boldsymbol{k-1}$

These AR processes can be put into state equations as follows:

$$\begin{cases} \underline{x}_T(k) = \mathbf{A}^{(\mathrm{T})}\underline{x}_T(k-1) + \underline{\omega}_T(k) \\ \underline{x}_\alpha(k) = \mathbf{A}^{(\alpha)}\underline{x}_\alpha(k-1) + \underline{\omega}_\alpha(k) \\ \underline{x}_\theta(k) = \mathbf{A}^{(\theta)}\underline{x}_\theta(k-1) + \underline{\omega}_\theta(k) \end{cases} \tag{2}$$

where $\underline{x}_T(k) = \left[\,x_T[1,1,k],\dots,x_T[I,J,k]\right]^T$ for $I*J$ grids and similarly for $\underline{x}_\alpha$ and $\underline{x}_\theta$. Matrices $\boldsymbol{A}^T,\boldsymbol{A}^\alpha$ and $\boldsymbol{A}^\theta$ are block Toeplitz of size $(IJ)*(IJ)$ with $a_{i,j}$s as their elements. Considering the same weight for equidistance neighboring cells, i.e. $a^T{}_{0,0} = \rho_0$, $a^T{}_{1,0} = a^T{}_{0,1} = a^T{}_{-1,0} = a^T{}_{0,-1} = \rho_1$ and $a^T{}_{1,1} = a^T{}_{-1,-1} = a^T{}_{-1,1} = a^T{}_{1,-1} = \rho_2$, matrix $\boldsymbol{A}^{(T)}$ in (3) is the right-stochastic version (each row is normalized by the sum of the elements) of the matrix $\boldsymbol{A}'^{(T)}$ given by

$$\boldsymbol{A}'^{(T)} = \begin{bmatrix} \boldsymbol{B} & \boldsymbol{C} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \boldsymbol{C} & \boldsymbol{B} & \boldsymbol{C} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{C} & \boldsymbol{B} & \boldsymbol{C} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \boldsymbol{C} & \boldsymbol{B} & \boldsymbol{C} & \mathbf{0} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \boldsymbol{C} & \boldsymbol{B} & \boldsymbol{C} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \boldsymbol{C} & \boldsymbol{B} & \boldsymbol{C} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \boldsymbol{C} & \boldsymbol{B} & \boldsymbol{C} \\ \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \mathbf{0} & \boldsymbol{C} & \boldsymbol{B} \end{bmatrix} \tag{3}$$

where matrices $\boldsymbol{B}$ and $\boldsymbol{C}$ are defined as

$$\boldsymbol{B} = \begin{bmatrix} \rho_0 & \rho_1 & 0 & 0 \\ \rho_1 & \rho_0 & \rho_1 & 0 \\ 0 & \rho_1 & \rho_0 & \rho_1 \\ 0 & 0 & \rho_1 & \rho_0 \end{bmatrix} \quad , \quad \boldsymbol{C} = \begin{bmatrix} \rho_1 & \rho_2 & 0 & 0 \\ \rho_2 & \rho_1 & \rho_2 & 0 \\ 0 & \rho_2 & \rho_1 & \rho_2 \\ 0 & 0 & \rho_2 & \rho_1 \end{bmatrix} \tag{4}$$

Here, ρ_0, ρ_1 and ρ_2 are estimated from several training snapshots using a Yule-Walker equation for 2-D AR models. We then concatenate $\underline{x}_T(k), \underline{x}_\alpha(k)$ and $\underline{x}_\theta(k)$ to form the new augmented state equation as

$$\underline{x}(k) = \boldsymbol{A}\underline{x}(k-1) + \underline{\omega}(k) \tag{5}$$

where $\underline{x}(k) = [\underline{x}_T(k)^T, \underline{x}_\alpha(k)^T, \underline{x}_\theta(k)^T]$, $\underline{\omega}(k) = [\underline{\omega}_T(k)^T, \underline{\omega}_\alpha(k)^T, \underline{\omega}_\theta(k)^T]$ and $\boldsymbol{A}$ is defined to be

$$\boldsymbol{A} = \begin{bmatrix} \boldsymbol{A}^{(T)} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \boldsymbol{A}^{(\alpha)} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \boldsymbol{A}^{(\theta)} \end{bmatrix} \tag{6}$$

Combining (3) with the nonlinear observation equation yields the state equations given by

$$\begin{aligned} \underline{x}(k) &= \boldsymbol{A}\underline{x}(k-1) + \underline{\omega}(k) \\ \underline{y}(k) &= H\left(\underline{x}(k)\right) + \underline{n}(k) \end{aligned} \tag{7}$$

where $\underline{y}(k)$ consists of all the measured ToA's and H is a known nonlinear function that relates the state to the observations (please refer to the previous report for more information on this observation equation). Using Eq. (3) and the training data (for the simulated only) we can estimate the statistics of $\underline{\omega}(k)$.

Using these new formulations that employ spatial AR model for the state evolution, we ran our UKF-based acoustic tomography method on the simulated data (generated in the previous quarter) and compared the results with those of simple random walk model. Figure 5 shows the actual (Figure 5(a)) and retrieved temperature results at one snapshot over the entire deployment field using the new formulation with spatial modeling (Figure 2(c)) and the previous method without the spatial modeling (Figure 5(b)). Significant improvements can be seen using the 2-D spatial model as the dynamic of the process when compared to the old results. This result is encouraging as we may be able to get even more accurate results using a better spatial model for the state evolution.

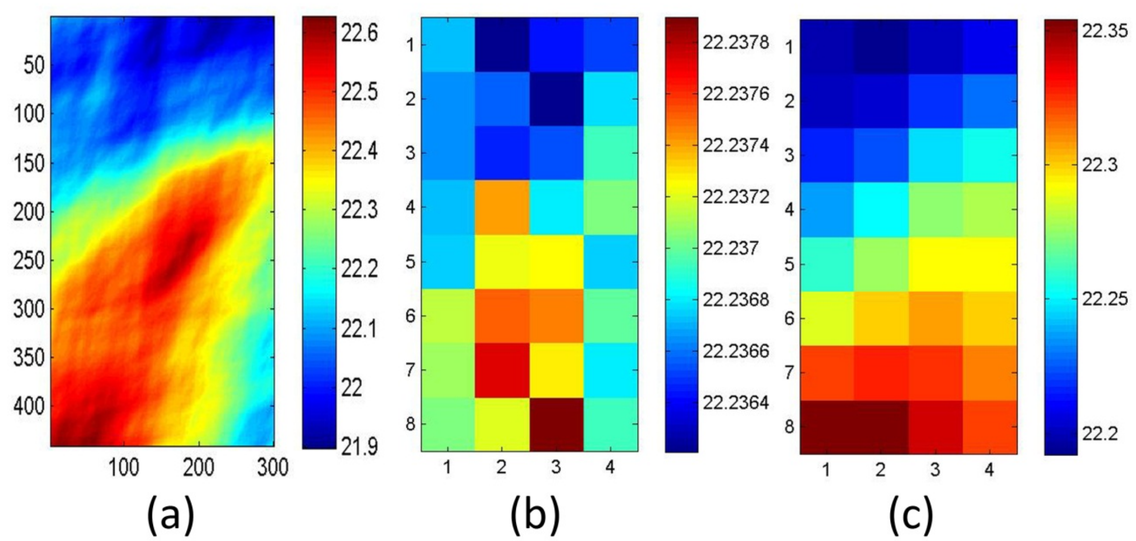

Figure 5. (a) The actual temperature field. (b) Reconstructed temperature field using random walk model. (c) Reconstructed temperature using 2-D spatial AR model as the state evolution equation.

In the past we used to notice singularity problems in computing the sigma points (Cholesky decomposition of the *a priori* error covariance matrix $P_{k|k-1}$ fails-please refer to the previous report for more information on the UKF process) in the UKF-based method when random walk model was used. This can be attributed to significant mismatch between the random walk model that assumes no dynamics for the states and the actual data. An important byproduct of this new formulation is that this singularity problem is completely solved by using the spatial AR model, which better captures the dynamics in the data. Figures 6, 7 and 8 show the MSE errors for temperature and the amplitude and angle components of wind velocity for both the random walk and 2-D spatial AR models. As can be seen, using the 2-D spatial AR model the UKF is converging better with smaller errors. This is particularly evident for temperature.

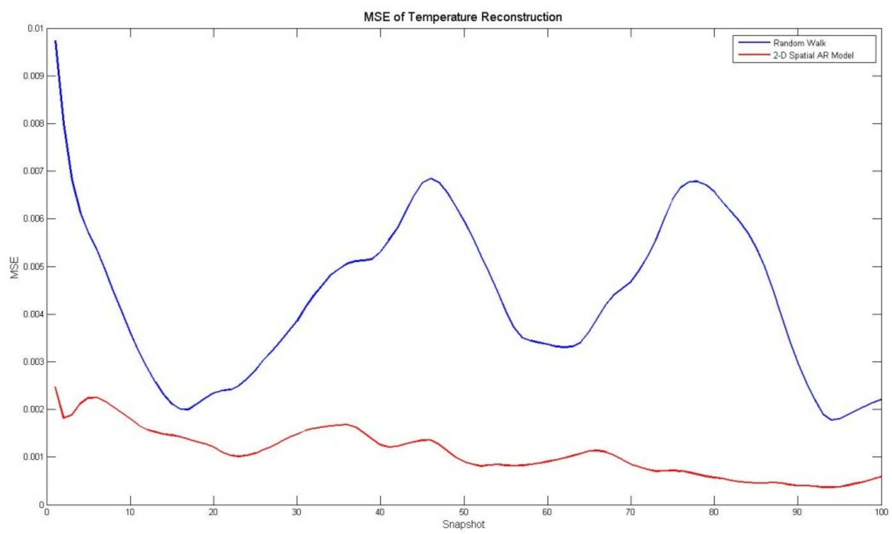

Figure 6. Mean Square Error (MSE) of temperature reconstruction.

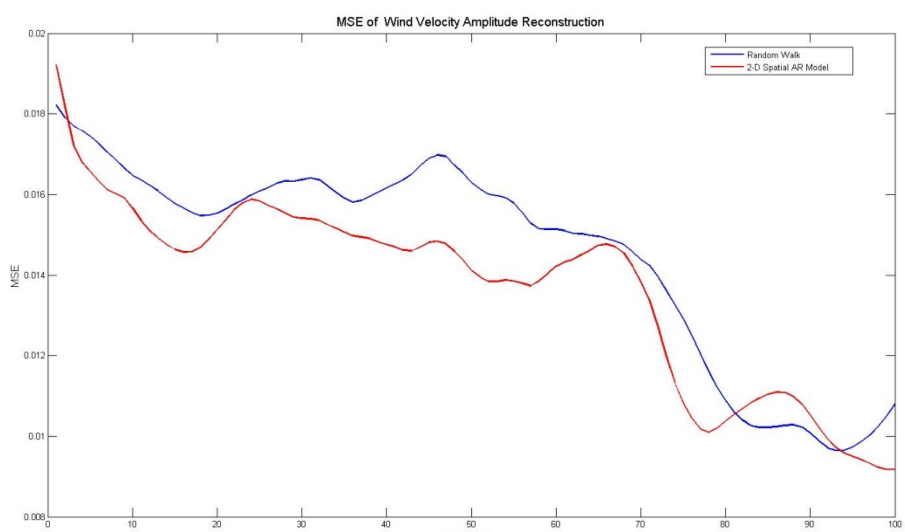

Figure 7. Mean Square Error (MSE) of wind velocity amplitude reconstruction.

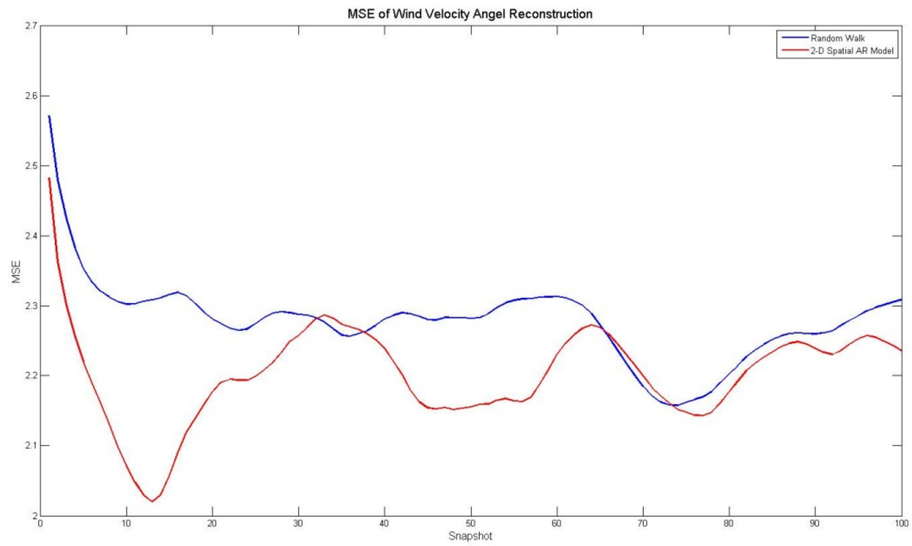

Figure 8. Mean Square Error (MSE) of wind velocity angel reconstruction.

Study of the Temporal Dynamic

A study on the temporal dependency of the states in different cells was carried out using the simulated data. The fields in each cell were treated as time series and an AR model was fitted to each time series using ITSM 2000. For almost all cells the best fitted model was found to be a second order AR of the following forms:

$$\begin{aligned} x_T[n,m,k] &= 1.97 * x_T[n,m,k-1] - 0.97 * x_T[n,m,k-2] + \omega_T[n,m,k] \\ x_\alpha[n,m,k] &= 1.988 * x_\alpha[n,m,k-1] - 0.988 * x_\alpha[n,m,k-2] + \omega_\alpha[n,m,k] \\ x_\theta[n,m,k] &= 1.988 * x_\theta[n,m,k-1] - 0.988 * x_\theta[n,m,k-2] + \omega_\theta[n,m,k] \end{aligned} \tag{8}$$

Or

$$\underline{x}(k) \approx 1.98 * \underline{x}(k-1) - 0.98 * \underline{x}(k-2) + \underline{\omega}(k) \tag{9}$$

The statistics of the noise are also found to be as

$$\underline{\omega} \sim N(\underline{0}, \begin{bmatrix} \sigma_T^2 \boldsymbol{I} & \mathbf{0} & \mathbf{0} \\ \mathbf{0} & \sigma_\alpha^2 \boldsymbol{I} & \mathbf{0} \\ \mathbf{0} & \mathbf{0} & \sigma_\theta^2 \boldsymbol{I} \end{bmatrix}) \tag{10}$$

with $\sigma_T^2 = 0.0288$, $\sigma_\alpha^2 = 0.0212$ and $\sigma_\theta^2 = 0.0265$. This modeling process will be further investigated in the next quarter.

Conclusions and Future Work

The experiments on the spatial-temporal behavior of the simulated data revealed that there is still a lot of room for improvements in our modeling process. Thus, among our next quarter goals are to investigate developing more accurate models for the data in both time and space and combine the temporal and spatial behavior of the data and come up with a 3-D AR model. It is expected that this combined spatial-temporal model will further improve the results presented in Section 2.

Additionally, we plan on implementing the TDSI method [4,5] on the simulated data and compare the performance of our method with that of the TDSI. Finally, we will prepare a draft of a journal paper on the results of our research so far.

References

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[2] P. J. Brockwell and R. A. Davis, *Introduction to Time Series and Forecasting*, vol. 39, no. 4. Springer, 2002, p. 434.

[3] O. Khorloo, Z. Gunjee, and B. Sosorbaram, "Wind Field Synthesis for Animating Wind-induced Vibration," *The International Journal of Virtual Reality*, vol. 10, no. 1, pp. 53-60, 2011.

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Travel

Sam Atwood arrived in Monterey on June 3 and reported to NRL shortly thereafter. He worked at the lab under the direction of Dr. Jeff Reid for the summer 2011, returning to CSU in August 2011 for the start of the Fall semester.

Swaroop Sahoo and two other Electrical and Computer Engineering graduate students Scott Nelson and Ishan Thakkar traveled to Lamont, Oklahoma, to conduct the HUMEX11 field experiment from July 5-15 and August 3-14.

Equipment/systems status

Nothing to report this period.

Research Theme: Remote Sensing of Battlespace Parameters

Administrative

None this period.

Research activity and/or results

Dr. Stanley Kidder
Continued working with John Forsythe and University of Michigan colleagues Dorit Hammerling and Yoichi Shiga to experiment with universal kriging as a technique to blend various Total Precipitable Water observations and to extract uncertainty estimates.

Gave a video teleconference presentation titled "Global Precipitation Products for Data-Denied Regions" to DoD colleagues on September 12. Met with AFWA representatives (Dr. Jeffrey Cetola and Mr. Steve Rugg) about AFWA's data needs on September 28.

Prof. William Cotton
The journal paper derived from Geoffrey Krall's MS thesis was placed in the Open Discussion web page of Atmospheric Chemistry and Physics (An Interactive Open Access Journal of the European Geosciences Union), following revisions in response to reviewers. It remains under review for publication by the journal.

Prof. Susan van den Heever and Robert Seigel
The manuscript titled "Dust Lofting and Ingestion by Supercell Storms" was successfully submitted to the Journal of Atmospheric Science in August.

Robert gave a presentation at the Mesoscale Conference in Los Angeles titled "Different approaches to modeling supercell mineral dust ingestion pathways." This presentation was very well received and good questions were raised after the delivery. In addition to the experience gained from giving a presentation, Rob also gained experience from interacting with various scientists within the community. The nature of the conference was of a more intimate setting and numerous networking opportunities took place.

Research and writing continues on the second manuscript titled "Simulated density currents beneath embedded stratified layers." Results from this experiment are quite promising and the hypothesis appears to be validated. Results indicate that the intrusion of a thin stable layer impacts the density current by lowering its head height and increasing its propagation speed. The physical mechanism for this process occurs from an increase in the surface pressure gradient due to mechanically driven adiabatic cooling within the stable layer. The cooling in the stable layer increases the surface pressure at the gust front from the increase in hydrostatic forces. These results are important for forecasting the time of arrival for many cold pool driven phenomena, such as haboob dust storms. The manuscript is nearing submission quality and will be submitted to Monthly Weather Review.

Lance Vanden Boogart
Prof. Vonder Haar and Lance have established that his thesis will focus on analyzing CIRA's total precipitable water anomaly (TPW Anomaly) dataset. One idea is to look at heavy rain and drought events over data-denied regions. The student has greatly improved his IDL proficiency over the summer and is now quite comfortable in the environment. The process of acquiring the TPW data has begun and Lance will start testing files for analysis in IDL. The course load for Fall semeser is much lighter, leaving more time for thesis research.

<u>Travel</u>

Rob Seigel traveled to Los Angeles July 8 - August 5 and presented his research results at the 14^{th} Conference on Mesoscale Processes of the American Meteorological Society.

<u>Equipment/systems status</u>

Nothing to report this period.

Research Theme: Technology Transition and Interactions

Prof. Thomas Vonder Haar, Recipient Program Manager, attended a meeting related to the DoD Center for Geosciences/Atmospheric Research at the Army Research Laboratory in Adelphi, Maryland on Tuesday, August 2.

Dr. Stanley Kidder gave a video teleconference presentation titled “Global Precipitation Products for Data-Denied Regions” to DoD colleagues on September 12. CSU researchers and students were in the audience at CIRA, while several participants from ARL Adelphi and WSMR, AFWA, and NRL Monterey utilized the VTC capabilities.

Prof. Niemann provided EOF-based soil moisture tool to Dr. George Mason at ERDC.

<u>Publications</u>

Jones, A.S., 2011: DPEAS Documentation Summary for DPEAS version 3.x, October, 6 pp.

Jones, A .S., S.Q. Kidder, and J.M. Forsythe, 2011: Data Processing and Error Analysis System (DPEAS) User’s Guide for DPEAS version 3.x, October, 46 pp.

Jones, A.S., S.Q. Kidder, and J.M. Forsythe, 2011: Data Processing and Error Analysis System (DPEAS) Programmers’s Guide for DPEAS version 3.x, October, 81 pp.

Jones, A.S., S.Q. Kidder, 2011: Data Processing and Error Analysis System (DPEAS) DPEAS Cross-sensor Processing Environment (CPE) Guide, Version 1.4, October, 30 pp.

Noh, Y.J., C.J. Seaman, T.H. Vonder Haar, D.R. Hudak, and P. Rodriguez, 2011: Comparisons and analyses of wintertime mixed-phase clouds using satellite and aircraft observations. *J. Geophys. Res*., 116, D18207, doi:10.1029/2010JD015420.

Noh, Y.J., C.J. Seaman, T.H. Vonder Haar, and G. Liu, 2011: In situ aircraft measurements of water content profiles in various midlatitude mixed-phase clouds. *J. Appl. Meteor. Climatol*. (submitted)

Sahoo, S., S.C. Reising, S. Padmanabhan, J. Vivekanandan, F. Iturbide-Sanchez, N. Pierdicca, E. Pichelli and D. Cimini, 2011: 3-D humidity retrieval using a network of compact microwave radiometers to correct for variations in wet tropospheric path delay in Spaceborne Interferometric SAR Imagery,” *IEEE Trans. Geosci. Remote Sensing*, vol. 49, no. 9, pp. 3281-3290 (Sept.)

<u>Presentations</u>

Andrew Jones presented “AFWA Collaboration Opportunities at CSU,” at CIRA, Fort Collins, CO, September 28.

Y. J. Noh presented “A comparison of wintertime precipitation characteristics using space and ground based radar data” at the 5th Workshop on Satellite Data Application for Global Environment Monitoring, NIMR/KMA, 28-30 September 2011, Gyeongju, Korea (oral presentation).

Robert Seigel presented “Different approaches to modeling supercell mineral dust ingestion parthways” at the AMS 14th Conference on Mesoscale Processes, July 8 - August 5, Los Angeles, CA.

Appendix 1

CG/AR Researchers under Cooperative Agreement W911NF-06-2-0015

Last Name	First Name	Department	E-mail	Specialty	Theme Area
Azimi-Sadjadi	Mahmood	ElecCompEngr	azimi@engr.colostate.edu	Neural Net Studies/Acoustics	Remote Sensing Battlespace/Urban BL
Carey	Lawrence	TAMU (sub)	carey@ariel.met.tamu.edu	Radar Meteorology/Cloud Microhysics	Clouds, Icing, and Aerosols Effects
Cheng	William	Atmos Science	cheng@atmos.colostate.edu	Mesoscale Modeling	Environmental Modeling and Assimilation
Combs	Cindy	CIRA	combs@cira.colostate.edu	Satellite/Climatology	Hydrometeorology/Battlespace Parameters
Cotton	William	Atmos Science	cotton@isis.atmos.colostate.edu	Atmospheric Modeling	Env Modeling/Battlespace Parameters
Eis	Kenneth	CIRA	eis@cira.colostate.edu	Satellite Meteorology	Technology Transition and Interactions
Fletcher	Steven	CIRA	fletcher@cira.colostate.edu	Data Assimilation Methods	Environmental Modeling and Assimilation
Forsythe	John	CIRA	forsythe@cira.colostate.edu	Satellite Meteorology/Data Analysis	Remote Sensing of Battlespace Parameters, Clouds, Icing, and Aerosols Effects
Fowler	Laura	CIRA	fowler@cira.colostate.edu	Cloud Microphysics/Data Assimilation	Environmental Modeling and Assimilation
Haynes	John	CIRA	haynes@cira.colostate.edu	Satellite Meteor/Cloud Precip Retrievals	Clouds, Icing, and Aerosols Effects
Jones	Andrew	CIRA	jones@cira.colostate.edu	Surface Moisture/Remote Sensing	Hydrometeorology, Environmental Modeling and Assimilation
Julien	Pierre	Civil Env Engr	pierre@lance.colostate.edu	Hydrology	Hydrometeorology
Kankiewicz	Adam	CIRA	kankie@cira.colostate.edu	Satellite Meteorology	Clouds, Icing, and Aerosols Effects
Kidder	Stanley	CIRA	kidder@cira.colostate.edu	Satellite Meterology/Remote Sensing	Remote Sensing of Battlespace Parameters
Knaff	John	CIRA	knaff@cira.colostate.edu	Tropical Met/Forecast Tech Develop	Remote Sensing of Battlespace Parameters
Kreidenweis	Sonia	Atmos Science	soniak@aerosol.colostate.edu	Aerosols	Clouds, Icing, Aerosols Effects/Urban BL
Larson	Vincent	UW-Mil (sub)	vlarson@uwm.edu	Cloud Modeling and Parameterization	Clouds, Icing, and Aerosols Effects
Longmore	Scott	CIRA	longmore@cira.colostate.edu	Modeling and Remote Sensing	Hydrometeorology/Environ. Modeling
Matsumoto	Cliff	CIRA	cliff.r.matsumoto@noaa.gov	Tropical Meteorology/Hurricane Motion	Technology Transition and Interactions
Miller	Steven	CIRA	miller@cira.colostate.edu	Satellite Instrumentation	Clouds, Icing, and Aerosols Effects
Niemann	Jeffrey	Civil Env Engr	jniemann@engr.colostate.edu	Hydrology/Soil Moisture	Hydrometeorology
Noh	Yoo-Jeong	CIRA	noh@cira.colostate.edu	SatMet/Cloud, Precipitation Retrievals	Clouds, Icing, and Aerosols Effects
Ostashev	Vladiimir	CU (sub)	vladimir.ostashev@noaa.gov	Atmospheric Acoustics	Remote Sensing of Battlespace Parameters
Pielke	Roger	CU (sub)	pielkesr@cires.colorado.edu	Mesoscale/Regional Wx Climate Studies	Urban and Boundary Layer Environment
Ramirez	Jorge	Civil Env Engr	ramirez@engr.colostate.edu	Hydrology, Hydrometeorology & Water	Hydrometeorology
Reinke	Donald	CIRA	reinke@cira.colostate.edu	Satellite Meteorology/Programming	Clouds, Icing, and Aerosols Effects
Reising	Steven	ElecCompEngr	steven.reising@colostate.edu	Boundary Layer/Remote Sensing	Urban and Boundary Layer Environment
Sengupta	Manajit	CIRA	sengupta@cira.colostate.edu	Radiative Transfer	Environmental Modeling and Assimilation
Stokowski	David	CU (sub)	david.stokowski@colorado.edu	Look-up Tables	Urban and Boundary Layer Environment
van den Heever	Susan	Atmos Science	sue@atmos.colostate.edu	Atmospheric Modeling/Cloud Physics/StormDynamics	Remote Sensing of Battlespace Parameters
Vonder Haar	Thomas	CIRA	vonderhaar@cira.colostate.edu	Satellite Meteorology	Technology Transition and Interactions
Zupanski	Dusanka	CIRA	zupanski@cira.colostate.edu	Data Assimilation Methods	Environmental Modeling and Assimilation
Zupanski	Milija	CIRA	zupanskim@cira.colostate.edu	Data Assimilation Methods	Environmental Modeling and Assimilation

CG/AR Graduate Students

Last Name	First Name	Department	E-mail	Theme Area	Advisor	Support
Atwood	Sam	Atmos Science	satwood@atmos.colostate.edu	Clouds, Icing, and Aerosols Effects/ Urban and Boundary Layer Environment	Kreidenweis	CG/AR
Busch	Frederick	Civil Environ Engr	frederick.busch@colostate.edu	Hydrometeorology	Niemann	CG/AR
Coleman	Michael	Civil Environ Engr	mike.coleman@colostate.edu	Hydrometeorology	Niemann	CG/AR
Donofrio	Kevin	Atmos Science	donofrio@cira.colostate.edu	Remote Sensing of Battlespace Parameters	Vonder Haar	CG/AR
Fidrych	Jonathan	Elect/Comp Engr	jonmfid@goku.engr.colostate.edu	Advanced Neural Net Processing of Acoustic Data	Azimi	CG/AR
Fields	Christopher	Civil Environ Engr	cmfields@engr.colostate.edu	Hydrometeorology	Niemann	CG/AR
Guillot	Eric	Atmos Science	guillot@cira.colostate.edu	Remote Sensing of Battlespace Parameters	Vonder Haar	CG/AR
Halgren	James	Civil Environ Engr	james.halgren@colostate.edu	Hydrometeorology	Julien	CG/AR
Howell	Kelly	Atmos Science	howell@cira.colostate.edu	Remote Sensing of Battlespace Parameters	Vonder Haar	CG/AR
Johnson	Kelley	Atmos. Science	kcjohnso@lamar.colostate.edu	Clouds, Icing, and Aerosols Effects	Kreidenweis	CG/AR
Kolouri	Soheil	Elect/Comp Engr	soheil.kolouri@colostate.edu	Urban and Boundary Layer Environment	Azimi	CG/AR
Krall	Geoffrey	Atmos Science	gkrall@atmos.colostate.edu	Environmental Modeling and Assimilation	Cotton	CG/AR
Leoncini	Giovanni	Atmos Science	leoncini@atmos.colostate.edu	Boundary Layer and Urban Studies	Pielke	CG/AR
Masarik	Matt	Atmos Science	mmasarik@atmos.colostate.edu	Environmental Modeling and Assimilation	Schubert/Vonder Haar	CG/AR
McCarron	Mike	Elect/Comp Engr	michael.mccarron@colostate.ed	Adv Neural Net Processing Acoustic Data	Azimi	CG/AR
Middlekauff	Steven	Civil Environ Engr	(unavailable)	Hydrometeorology	Niemann	CG/AR
Nobis	Timothy	Atmos Science	timothy.nobis@afwa.af.mil	Boundary Layer and Urban Studies	Pielke	AFIT
Potter	Lauren	Atmos Science	lepotter@atmos.colostate.edu	Urban and Boundary Layer Environment	Kreidenweis	CG/AR
Ram	Jessica	Atmos Science	ram@cira.colostate.edu	Remote Sensing of Battlespace Parameters	Vonder Haar	CG/AR
Rapp	Dustin	Atmos. Science	rapp@cira.colostate.edu	Soil Moisture WindSat	Vonder Haar	CG/AR
Roy	Gavin	Atmos. Science	gavin.roy@colostate.edu	Urban and Boundary Layer Environment	Vonder Haar	CG/AR
Sahoo	Swaroop	Elect/Comp Engr	swaroop.sahoo@colostate.edu	Urban and Boundary Layer Environment	Reising	CG/AR
Seaman	Curtis	Atmos Science	seaman@cira.colostate.edu	Clouds, Icing, and Aerosols Effects	Vonder Haar	CG/AR
Schwartz	Aaron	Atmos Science	schwartz@cira.colostate.edu	Clouds, Icing, and Aerosols Effects	Vonder Haar	CG/AR
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Smith	Michael	Atmos Science	msmith@atmos.colostate.edu	Environmental Modeling and Assimilation	Cotton	CG/AR
Steininger	Andrew	Civil Environ Engr	andy.steininger@colostate.edu	Hydrometeorology	Julien	CG/AR
Werbylo	Kevin	Civil Environ Engr	kwerbylo@engr.colostate.edu	Hydrometeorology	Niemann	CG/AR
Wichern	Gordon	Elect/Comp Engr	gwichern@engr.colostate.edu	Adv Neural Net Processing Acoustic Data	Azimi	CG/AR

Appendix 2
Publications

(The following were supported under CG/AR Cooperative Agreement W911NF-06-2-0015. Readers may also want to review the publications list from the previous Cooperative Agreements, DAAD19-02-2-0005, DAAD19-01-2-0018 and DAAL01-98-2-0078.)

Carey, L.D., J. Niu, P. Yang, J.A. Kankiewicz, V.E. Larson, and T.H. Vonder Haar, 2008: The vertical profile of liquid and ice water content in midlatitude mixed-phase altocumulus clouds. *J. Appl. Meteor. Clim.*, 47, 2487-2495 (doi: 10.75/2008JACM885.1).

Combs, C.L., D. Rapp, A.S. Jones, and G. Mason, 2007: Comparison of AGRMET model results with *in situ* soil moisture data. Pre-print CD-ROM, 21st Conference on Hydrology, January 14-18, San Antonio, TX (AMS).

Donofrio, K.M., 2007: A 1DVAR optimal estimation retrieval of water vapor profiles over the global oceans using spectral microwave radiances. Masters thesis, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, 165 pp.

Fletcher, S.J., 2010: Mixed Gaussian-lognormal four-dimensional data assimilation. *Tellus,* 62A, 266-287.

Fletcher, S.J., and M. Zupanski, 2007: An alternative to bias correction in retrievals and direct radiances assimilation. Pre-print CD-ROM, 11th Symposium on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface (IOAS-AOLS), January 13-19, San Antonio, TX (AMS).

Fletcher, S.J., M. Zupanski, and T.H. Vonder Haar, 2007: Lognormal Data Assimilation: Theory and Applications. Proceedings CD, Battlespace Atmospheric and Cloud Impacts on Military Operations Conference (BACIMO) 2007, November 6-8, Chestnut Hill, MA. Oral presentation, Session 2: Data Assimilation and Numerical Modeling.

Fletcher, S.J., and M. Zupanski, 2007: Implications and impacts of transforming lognormal variables into normal variables in VAR. *Meteorolgische Zeitschrift*, 16, 755-765.

Fletcher, S.J., and M. Zupanski, 2008: A study of ensemble size and shallow water dynamics with the Maximum Likelihood Ensemble Filter. *Tellus,* 60A, 348-360.

Forsythe, J.M., S.Q. Kidder, A.S. Jones, and T.H. Vonder Haar, 2007: Moisture profile retrievals from satellite microwave sounders for weather analysis over land and ocean. Proceedings (CD-ROM), The Joint 2007 EUMETSAT Meteorological Satellite Conference and the 15th American Meteorological Society (AMS) Satellite Meteorology and Oceanography Conference, September 24-28, Amsterdam, The Netherlands.

Forsythe, J.M., E.M.Guillot, and T.H. Vonder Haar, 2010: Improving cloud Nowcasting with satellite imagery via incorporation of cloud type. 14th Conference on Aviation, Range, and Aerospace Meteorology, January 17-21, Atlanta, GA (AMS) (poster).

Gaiser, P., A. Jones, L. Li, G. Mason, G. McWilliams, M. Mungiole, 2007: Improving the effectiveness of determining soil moisture using passive microwave satellite imagery. White paper to the National Polar-orbiting Operational Environmental Satellite Systems (NPOESS) Integrated Program Office (IPO), 14 pp.

Guillot, E.M., 2010: Evaluating satellite-based cloud persistence and displacement Nowcasting techniques over complex terrain. Masters thesis, Department of Atmospheric Science, Colorado State University, 105 p.

Guillot, E.M., T.H. Vonder Haar, and J.M. Forsythe, 2011: Evaluating satellite-based cloud persistence and displacement Nowcasting techniques over complex terrain. *Weather and Forecasting*, (submitted).

Howell, K.M., 2010: Quasi-global and regional water vapor and rainfall rate climatologies for a 35 month period. Masters thesis, Department of Atmospheric Science, Colorado State University, Fort Collins, Colorado, 123 p.

Jones, A.S., 2008: What is data assimilation? A tutorial. AMS Data Assimilation Education Forum, January 21, New Orleans, LA.

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